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Spatial shifts in salmonine harvest, harvest rate, and effort by charter boat anglers in Lake Michigan, 1992–2012

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ABSTRACT

Stocked and naturally reproducing salmonids in Lake Michigan support an economically important charter boat fishery which operates from multiple locations around the lake. Charter boat operators depend on the sustainability and spatial availability of salmonid species. We analyzed the spatial distributions of charter boat harvest of brown trout, Chinook salmon, coho salmon, lake trout, and rainbow trout from 1992 to 2012. We found that during this 21 year period fishing effort shifted closer to shore, to the west, and to the north. Harvest of some species, namely lake trout and rainbow trout, shifted towards shallower bottom depths and closer to shore. In contrast, harvests of Chinook and coho salmon have not shifted closer to shore in a consistent manner. We suggest that a variety of factors may have contributed to these trends in harvest patterns, including recent ecosystem shifts in Lake Michigan. While we acknowledge that spatial harvest patterns are unlikely to precisely mirror salmonid distribution patterns, we believe that reporting coarse shifts in harvest has implications for future management options including, but not limited to, stocking decisions and harvest regulations.

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Introduction

Salmon and trout (salmonids) contribute to the economically important recreational fishing industry throughout the Laurentian Great Lakes. In Lake Michigan, harvest of five species of salmonids (brown trout (*Salmo trutta*), Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), lake trout (*Salvelinus namaycush*), and rainbow trout (*Oncorhynchus mykiss*)) by charter boat operators constitutes a large proportion of both harvest (Benjamin and Bence, 2003; Brofka and Dettmers, 2001) and the economic benefit of the fishery (Melstrom and Lupi, 2013). Changes in the spatial distributions of salmonids and the locations of harvest have important implications for individual charter operators, as broad shifts in salmonid spatial distributions and catch rates can threaten the livelihood of local, individual charter operators. At the same time, charter operators are expected to alter where they fish and harvest salmonids in response to shifts in spatial distributions and catch rates. In fact, past studies in various systems have tracked changes in spatial distributions of fishing effort (Swain and Wade, 2003) and harvest (Benjamin and Bence, 2003; Vignaux, 1996) to infer changes in species distributions, essentially assuming that fishers act as rational agents.

Over the past several decades, the Lake Michigan ecosystem has experienced a large number of biotic and abiotic changes which may influence spatial structuring of biota and ultimately affect distributions of the lake's salmonid top predators and the fisheries that depend on them. Specifically, reduced nutrient loading, various species invasions, and altered climatic conditions may have affected biotic distributions across various spatial axes and scales. Similar to other areas of the Great Lakes (e.g., Lake Superior; Austin and Colman, 2007), Lake Michigan water temperatures have increased in past decades due to warmer air temperatures, resulting in shorter ice coverage (Jensen et al., 2007; McCormick and Fahnenstiel, 1999). Simultaneously, due to aggressive nutrient abatement programs, total loadings of phosphorous to Lake Michigan have generally declined since the early 1970s (Dolan and Chapra, 2012). These physico-chemical changes, coupled with the arrival and expansion of several invasive species, have led to a series of broad-scale biological changes. Perhaps most importantly, the introduction and expansion of dreissenid mussels (first, zebra mussel *Dreissena polymorpha*, now largely replaced by the quagga mussel *Dreissena rostiformis bugensis*) has seemingly contributed to not only an overall decline in seasonal water column primary producers (Pothoven and Fahnenstiel, 2013; Yousef et al., 2014), but also a relative increase in the importance of nearshore production (Fahnenstiel et al., 2010). In addition to a dramatically decreased spring phytoplankton

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bloom (Fahnenstiel et al., 2010; Vanderploeg et al., 2010; Yousef et al., 2014), summer chlorophyll concentrations decreased significantly between 1995–2000 and 2007–2011 (Pothoven and Fahnenstiel, 2013). The potential for dreissenid mussels to contribute to a nearshore shunt in productivity has been highlighted by Hecky et al. (2004). While the extent to which nearshore water column primary production has actually increased over time is unclear, nearshore production appears to have increased relative to offshore production (Brooks and Zastrow, 2002; Fahnenstiel et al., 2010; M. Hutton, Purdue University, personal communication). Moreover, it is apparent that nearshore benthic algal production (especially *Cladophora*) has recently increased (Shuchman et al., 2013), and several studies have highlighted the role of dreissenid mussels in facilitating this increase (Auer et al., 2010; Higgins et al., 2008; Tomlinson et al., 2010).

Not only have physico-chemical conditions and primary production changed in Lake Michigan, but there have also been reported shifts in relative abundances of many consumers and altered trophic interactions. For example, the formerly dominant benthic amphipod, *Diporeia* spp., has declined in abundance by multiple orders of magnitude (Nalepa et al., 2009) and invasive predatory zooplankton (*Bythotrephes longimanus* and *Cercopagis pengoi*) have increased in abundance and become important lake-wide planktivores (Yurista et al., 2010). Historically, invasive alewife (*Alosa pseudoharengus*) have served as both a dominant planktivorous fish in Lake Michigan and the main component of piscivorous salmonid diets (Jacobs et al., 2013; Savitz, 2009; Warner et al., 2008). However, similar to other small-bodied potential prey fish species, such as rainbow smelt (*Osmerus mordax*) and bloater (*Coregonus hoyi*) (Jacobs et al., 2013), alewife biomass in Lake Michigan has generally declined since the 1970s (Tsehaye et al., 2014). An exception to this trend is the nearshore, invasive, benthivorous round goby (*Neogobius melanostomus*), whose abundance has generally increased since arrival in Lake Michigan during the 1990s (Kornis and Vander Zanden, 2010). In turn, some salmonids, especially lake trout, have shifted their diets from consuming primarily alewife to consuming large numbers of round goby throughout the Great Lakes (Dietrich et al., 2006; Jacobs et al., 2010). While this shift in trophic connections is consistent with a system-wide shift towards increased reliance on nearshore and benthic production and decreased reliance on offshore, pelagic production (Rush et al., 2012; Turschak et al., 2014), it is unlikely that all salmonids are equally flexible in their prey consumption patterns. Some salmonid species (i.e., brown trout, lake trout, rainbow trout) display quite varied diets in the Great Lakes (Jacobs et al., 2010; Lantry, 2001; Roseman et al., 2014; Tsehaye et al., 2014) and are likely to consume nearshore fish prey such as round goby (Roseman et al., 2014). Other species (i.e., Chinook and coho salmon) are seemingly less plastic in prey consumption patterns (Savitz, 2009). In fact, Jacobs et al. (2013) demonstrated that the proportion of alewife in Chinook salmon diets in Lake Michigan increased from 1994–1996 to 2009–2010, even though alewife biomass declined during this time period.

Seasonal and inter-annual distributions of these potential prey species could also help to explain spatial trends of salmonid species. Seasonally, various fish species of the Great Lakes, including round goby (Walsh et al., 2007), display shifts to offshore, benthic habitats in the colder winter months. Salmonids may track these forage fishes as they move closer to shore from spring to fall. We are unaware of pronounced, inter-annual shifts in spatial locations of Lake Michigan forage fishes. For example, there has been no obvious shift in depth of capture for alewife in Lake Michigan in recent decades (C. Madenjian, USGS, personal communication). However, annual spatial shifts of forage fishes have been documented in other Laurentian Great Lakes since the arrival of dreissenid mussels (Mills et al., 2003; O'Gorman et al., 2000) and may have occurred in Lake Michigan. Moreover, changes in relative abundance of different forage fishes would lead to spatial changes in overall forage fish biomass.

While spatial shifts in salmonid harvest may partially reflect shifts in salmonid distributions, harvest patterns may also be strongly influenced by variation in catchability, fishing regulations and angler behavior. For example, catchability of fish may respond to ambient water temperature, water clarity, and local foraging opportunities (Danzmann et al., 1991; Gregory and Levings, 1998). In Lake Michigan, angler harvest limits for each salmonid species are related to harvest of other salmonid species, and thus spatial harvest patterns among salmonid species are likely co-dependent. Finally, considerations such as fuel costs and local harvest rates may affect when and where charter boat anglers target salmonids.

Herein, we present an analysis of spatial patterns of salmonid harvests by charter boat fishers in Lake Michigan from 1992 to 2012. Given that the assumption of constant catchability across space and time likely does not hold for charter boat fishers targeting salmonids in Lake Michigan, analysis of charter boat catch data is an imperfect way to assess changes in spatial distributions of salmonids. However, quantifying spatial patterns of salmonid harvest allows us, at a minimum, to assess if spatial trends in harvest patterns are qualitatively consistent with shifts in salmonid distributions expected to have occurred in response to ecosystem level changes. More directly, documenting spatial patterns of harvest may have implications for jurisdiction-specific stocking practices and harvest expectations. To these ends, we analyzed Lake Michigan charter boat harvest data (1992–2012) for trends in mean A) total water column depth, B) distance to shore, C) longitude, and D) latitude of salmonid harvest.

Methods

Charter boat harvest data

We compiled data collected by the Illinois Department of Natural Resources (ILDNR), Michigan Department of Natural Resources (MIDNR), and Wisconsin Department of Natural Resources (WIDNR) that describe charter boat harvest from May to September during 1992–2012 (excluding 1992 for ILDNR). These data describe individual charter boat trips and include the date, number of anglers, hours of effort, number of each species of fish harvested, and location (defined as the $10' \times 10'$ grid cell that was fished; Fig. 1). Each charter captain is required to report these data for each trip, and only one grid cell is reported for each trip. Catch and release data were seldom recorded, especially early in the study period, making it impossible to calculate and use catch rates as estimates of distribution. Information on species targeted during a fishing trip was not consistently recorded. Therefore, to reduce the impact of trips when non-salmonids were targeted, we excluded trips in which ≥20 yellow perch (*Perca flavescens*) were harvested (4299 trips excluded). Most of these excluded trips resulted in the harvest of zero or few salmonids (2567 individual harvested salmonids excluded). When <20 yellow perch were harvested, the rate of salmonid harvest increased to a point where it was appropriate to place a somewhat arbitrary threshold as to not exclude further data. We also omitted trips in which zero total salmonids were harvested because there was no indication of the targeted species; in many of these cases, fishing effort (angler-hours) was low (16,061 trips excluded). Moreover, several of our analytical methods evaluate the spatial location of salmonid harvest and were not affected by trips in which zero salmonids were harvested. Our final data set ($N = 520{,}441$ trips) consisted of 83,363 trip records from ILDNR, 214,170 trip records from MIDNR, and 222,908 trip records from WIDNR.

Data analysis

Our analysis focused on five salmonid species: brown trout (BNT), Chinook salmon (CHS), coho salmon (COS), lake trout (LAT), and rainbow trout (RBT). To visualize spatial patterns, we calculated harvest per unit effort (HPUE, using angler-hours as the index of

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